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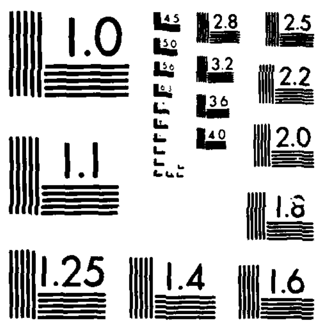

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Monterey, California

Man-Machine Systems of the 1990 Decade:
Cognitive Factors and Human Interface Issues

by

Paul J. Hoffman

August 1985

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This paper presents the primary psychological concepts which are fundamental to the design of man-machine interfaces for intelligent systems of the 1990's. These concepts embrace perception, learning, motivation, and cognitive capacities of human operators, in systems which require a high degree of operator-machine interaction. The central role of feedback is emphasized through simple schematic

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examples, designed to provide an understanding of the reciprocity requirements in man-machine communication.

Cognitive theory and recent experimental data form the basis for discussion of visual image storage, short-term memory, long-term memory, transfer rates and buffering of information being processed by the human operator, under control of a "central processor" with a cycle time of roughly 70 milliseconds.

Systems of the 1990 era will provide increased capability for high-speed processing of data and will utilize increasing numbers of decision-aides, spreadsheets and AI tools. Users of these systems will be components of networks, linked via efficient communication systems to other users and other subsystems. These developments will lead to fundamental changes in the work place, first in elimination of substantial amounts of high-volume, routine human operations, and then in the addition of non-routine, increasingly demanding, high risk decision-making and oversight control. These changes will lead initially to productivity gains, but this will be followed by dramatic changes in workforce requirements, with negative implications for full employment and worker satisfaction. It is held that attention to these broader issues can themselves provide guidance for design specifications for the user interface.

MAN-MACHINE SYSTEMS OF THE 1990 DECADE:
COGNITIVE FACTORS AND HUMAN INTERFACE ISSUES.

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I THE COUPLING OF MAN AND MACHINE

An important sign of progress in this age of technological breakthroughs is the fact that engineers and psychologists are beginning actively to share their respective knowledge and skill, towards the design of advanced man-machine interfaces. This has come about because of a growing awareness that machines must be conceptualized less as devices which exist apart from (and used by) operators, and more as systems which include human components as well as mechanical and electronic components.

It would not be an exaggeration to observe that the coupling of man and machine is much like a marriage. In both instances, there are interface problems, communication problems, role-identity problems and authority problems. Indeed, the recognition of the human being as an integral part of a single dynamic system is fundamental to the design of individualized (tailored) systems, and of work itself.

We have been taught that marriages are often unsuccessful if one partner dominates the other, or if there is a failure to communicate, or a misunderstanding of purpose. The consequences of inappropriate coupling of person to person can lead to frustration, anger, and even divorce. The consequences of inappropriate man-machine coupling are

likewise severe, and they are more widely experienced, if only because these mistakes are multiplied. Once the machine is designed, a production run can produce tens of thousands of them, all with the same deficiencies; all able to influence the lives of the hundreds of thousands of people who must be coupled to them. This paper is in part a commentary on the respective roles of man and machine, in an endeavor to identify certain concepts which stem from the field of psychology, which are capable of being incorporated into systems design concepts, and which must be clearly understood if the marriage between man and machine is not to end in frustration or disaster.

II THE SIMPLEST MAN-MACHINE SYSTEMS

How many of you have ever asked yourselves, "What is the simplest example of a man-machine system?" Our first thoughts about this question are in terms of complicated flow diagrams with arrows describing communications which flow between boxes, and each box is either an object, a machine, a person, or a process. But how simple can a system be, and still be a system? If Neanderthal Man is married to his coup de poing, is that a "system"? How about you and your wristwatch? Is that a system? Many people would describe the man-machine relationship in terms of one of the configurations shown in Figure 1.

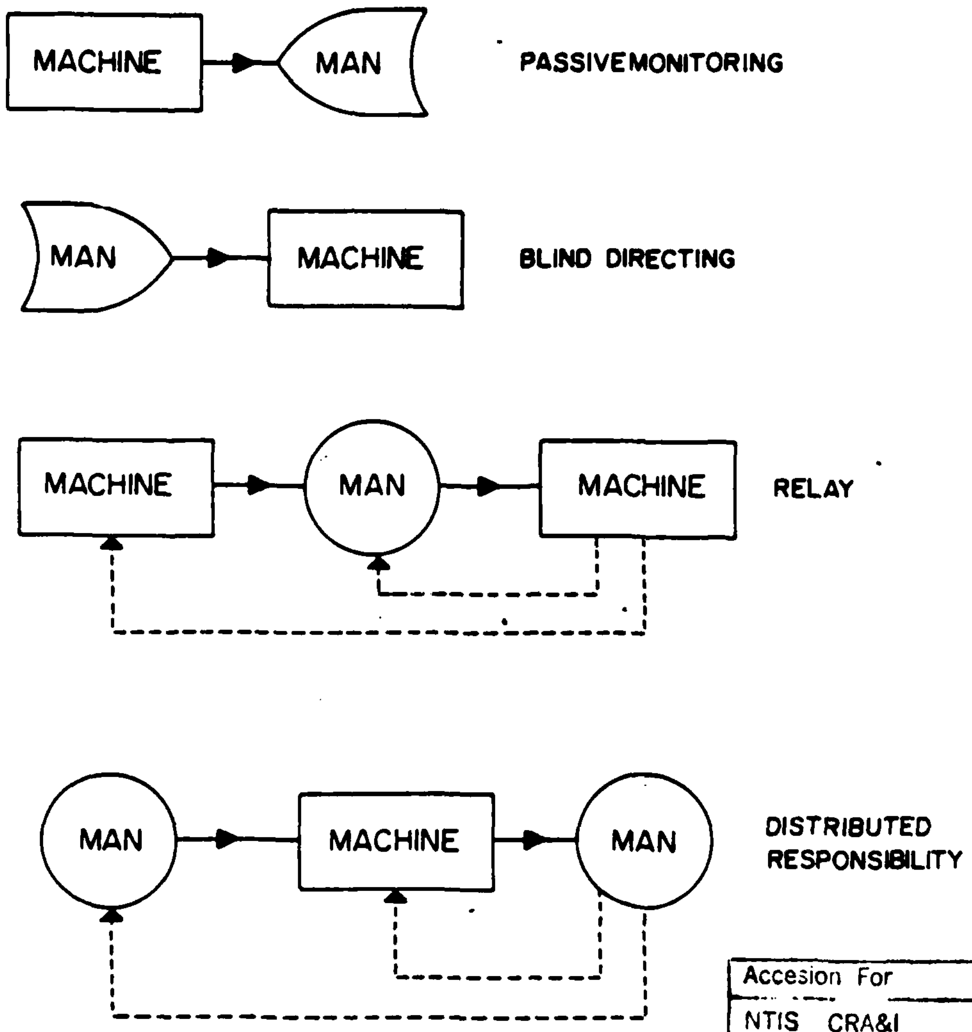

Figure 1. Simple conceptions of Man-Machine Systems

The configuration at the top of the Figure illustrates a machine displaying information to an "operator". I have labelled this passive monitoring because a) the flow of information is from the machine to the operator, and b) it is not clear what the operator is going to do about it. This illustration may be likened to the wristwatch-human configuration. It is as though the machine is the alarm clock and the human is asleep until the alarm goes off. The limitations of this representation should be obvious. The clock acts as a mechanism for awakening the human, but the clock and the person together do not constitute a system.

The second configuration of Figure 1 is simply the reverse of the first. Here, the operator is providing information to the machine, but God knows what the machine is doing with it. I have labeled this blind directing. It is not a system either. And it is certainly not "friendly". After all, a machine cannot be friendly if it will not communicate with you, or even acknowledge your instructions.

In this paper, I will make occasional reference to certain characteristics of systems which can evoke emotional and motivational responses in users, rather than focusing exclusively upon efficiency and optimality of systems, for the distinctively psychological aspects of human behavior are seldom included in our thinking about design requirements. Friendliness is one such psychological aspect. There are others as well, as we shall see.

In the third illustration, the operator is depicted as receiving information from one machine, then transmitting information to a second machine. In this instance, the operator functions as a relay

station between two machines. In this capacity, the operator can serve a useful purpose only if able to interpret information produced by the first machine in a manner that is beyond the machine's capabilities. As an example, think of the first machine as a radio telescope, tracking celestial phenomena and outputting analog information; think of the second machine as a video camera which is adjusted by the operator in response to tracking information. I have sketched broken arrows to suggest feedback loops from the second machine to the operator, and to the first machine. Another loop can exist between the operator and the first machine. Without one of these loops, the configuration is not a system, for there is no dynamic control. Add the loop, and it is.

At the bottom of the page, we show the reverse case. Human input to a machine; and machine output to another person. What does this represent in the real world? If the machine is a telephone, or a messaging system, it can serve the function of facilitating communication between two people. Now what of the psychological factors implicit in this system? Is it friendly? Here we have two people, A and B, and a machine, engaging in exchange of information. Person A tries to transmit information to the machine, but receives no acknowledgement from it. Instead, acknowledgement comes from another party; namely, person B, who has engaged in a prior discussion with the machine. Since person A feels entitled to some degree of control over the machine, the arrangement will surely lead to resentment. In somewhat similar circumstances, Person B attempts to reach agreement with the machine, which, not being a dedicated slave to B, continues

to service person A's input as well, and to be modified by that input in some way beyond B's control. Here, person B will likely experience some degree of irritation and jealousy. It is instructive to understand that by changing the directions of the broken arrows, one alters not only the formal system configuration, but the psychological dynamics as well.

III ESSENTIALITY OF FEEDBACK

How essential is feedback? When was the last time you called a number and found yourself talking to the wrong party? Without a feedback loop, you would never know the difference. It is fundamental to systems theory that without feedback, you cannot have a system. Without feedback, neither man nor machine is capable of control, of tracking, of learning, or of wise decisions. I am sure that I am restating the obvious about dynamic systems and feedback loops. If so, it is because of my concern that many people have distorted views of what systems and machines really are and about how they ought to be designed. Let me show you the intuitive view that many people hold about machines.....that is, until they begin thinking about them seriously.

In Figure 2 we display several systems. In the system portrayed at the top left, it is clear that the operator dominates the machine. It is like driving a tractor, or operating a power drill. Notice that the process is shown apart from the machine, and that there is a broken arrow between the operator and the process. The broken arror implies a feedback mechanism. Note also that there are

THREE CONCEPTIONS OF A MAN-MACHINE SYSTEM

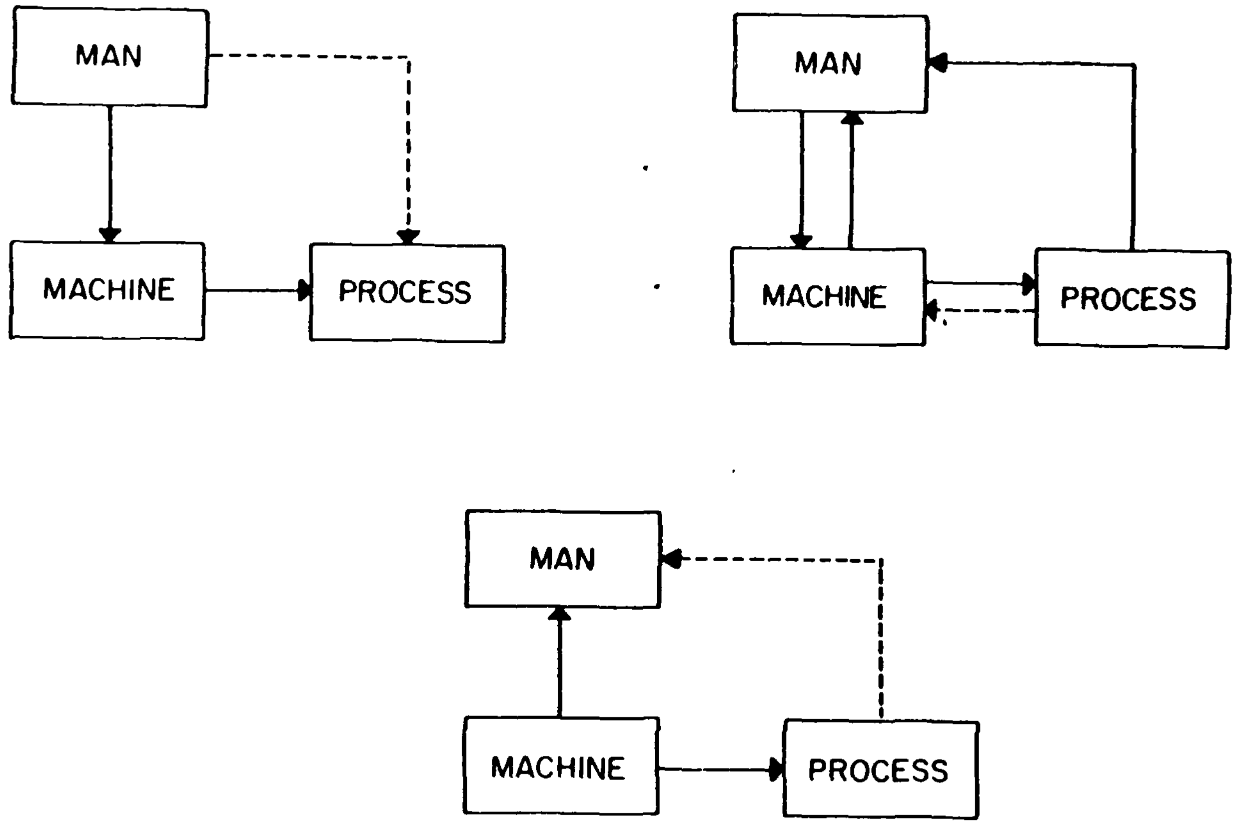

Figure 2. Systems with and without appropriate feedback mechanisms.

no arrows returning from the machine to the operator or from the process to the operator. I once listened to an engineer explain that this diagram correctly represented a man-machine system. Her rationale was somewhat as follows:

> "After all, when you operate a machine, YOU direct IT....you give it commands, you give it information. The machine does not give YOU commands or information. Then, to evaluate your work, you inspect the process. The process does not look at you. When you drive a tractor, or operate a power drill, or a typewriter, you are in charge of the machine, and you are in charge of the process".

This viewpoint is totally incorrect. As we have emphasized, one cannot have an adaptive system without feedback. Whether the operator is driving a tractor, operating a word-processor, or working on an assembly line, it is fundamental that a continual stream of feedback be received; from the machine, from the environment, and from the process. Therefore, we must conceptualize man-machine systems as becoming increasingly able to communicate; i.e., by transmission of information from operator to machine and from machine to operator.

Just such a situation is depicted by the system shown to the right of Figure 2. A flow of information is being tracked by the operator's visual and other senses. This information is processed into decisions and actions which ONLY THEN lead to corrective actions. Feedback through the operator's sensory organs enables the operator to input adjustments via the control console of the machine. Without such feedback there is obviously no sense in which

one can control processes, unless one is willing to assume 100% accuracy in the initial energizing commands transmitted to the machine, and unless the machine is 100% reliable in carrying them out. The system shown on the right simply emphasizes the role of the operator as a component of the control-feedback loop.

The system depicted at the bottom of Figure 2 represents some of our worst fears about the future. This is Hal, from 2001: Space Odyssey; a system which senses man <u>and</u> process, which controls both, and which is incapable of benefiting from feeback, either from man or from the environment. While it seems far-fetched, this kind of system becomes a real possibility when two events occur: 1) expert systems and large data acquisition systems are incorporated into machines; and 2) the machines are turned over to unsophisticated users. Under these conditions, it is predictable that users will be overwhelmed by the power, knowledge, speed of response and objectivity of the machine. They will then be either unable or unwilling to exercise their own judgment, for they believe that the system which they are operating is wiser then they. When operators come to believe this, they are no longer operating the system; the system is dominating them.

It is unfortunate that so many people have mistaken beliefs about systems. They tend to think that the loop is not closed. The role of feedback is not recognized. When it is recognized, it is often in terms of the <u>result</u> of the action, not as guidance during a process of interaction. In addition, people (even sophisticated engineers who should know better) frequently discount the importance of status displays, error messages, acknowledgements and queries. Though these

are vital feedback components for the operator, they are more frequently thought of rather as "windows" through which the engineer can "look inside" the machine. The layout of controls is also often given insufficient study. It is assumed that weaknesses of the system are due simply to weaknesses of operators who should be able quickly to master the machine, however ill-conceived the display panels, controls, and interface software.

IV ARTICULATED COMMUNICATION NETWORKS

Engineers do understand communication networks. Perhaps the earliest and most naive representation of systems looked something like that shown in Figure 3.

Here we see two components which are linked. The I/O channel is simply a representation of each component transmitting information to the other, and each receiving information from the other. The communication interface is not articulated in the Figure and is barely implied. In contrast with the past, the requirements for communication interfaces have become better understood. The systems in production today are often very sophisticated, extremely reliable and powerful. In their design, attention has been given to channel capacity, baud rates, protocols, bit codes, buffer size, data transfer rates, and redundancy checks. It does not appear that we can learn much from Figure 3. It is nothing more than two subsystems linked so as to function as a single integrated system.

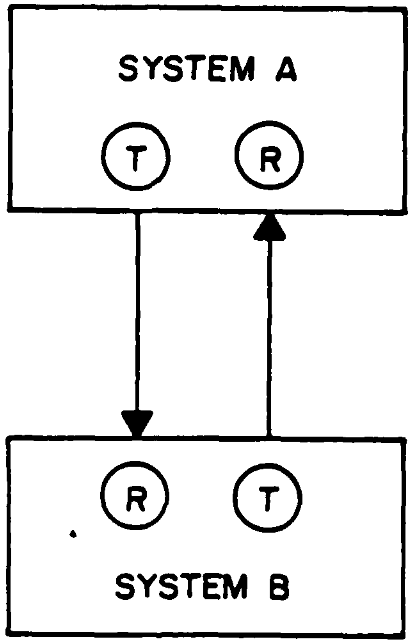

Figure 3. Earliest view of an interface between two systems.

Adapted from Card, S.K., Moran, T.P., and Newell, A., The Psychology of Human-Computer Interaction, Hillsdale, N.J., Erlbaum Associates, 1983.

Figure 4. Another form of "two-system" interfacing.

There is a great deal to learn when we assume that one of the two sub-systems shown in Figure 3 is human. This is illustrated by the system displayed in Figure 4. Needless to say, Figures 3 and 4 are exactly analogous.

In the present case, however, the operator is one sub-system or component, and the terminal is a part of his interface to the second component, an information processing machine of some kind. Just as in Figure 3, it is possible to talk about transmission and reception of information from each component to the other. As in Figure 3, we need to give attention to encoding and decoding of information, buffering, data transfer rates, channel capacity and redundancy. The difference is the need to conceptualize our thinking about human systems in the language of psychology: the psychophysiology of vision and audition, the parameters of human performance, as derived from cognitive psychology, the principles of forgetting, recall, association, kinesthetic responses, experimental psychophysics and human information processing characteristics. In too many instances, the requisite principles of psychology and the parameters of human performance characteristics are known to human factors psychologists, yet not to interface design teams in industry, as a result of which these factors are often ignored in the design of the interface.

While most interface design teams now recognize the parallelism that exists between those design considerations which apply to the human component and those which apply to the machine component, many do not. One can begin to appreciate the parallelism by developing schematics of the sort I have drawn as Figure 5.

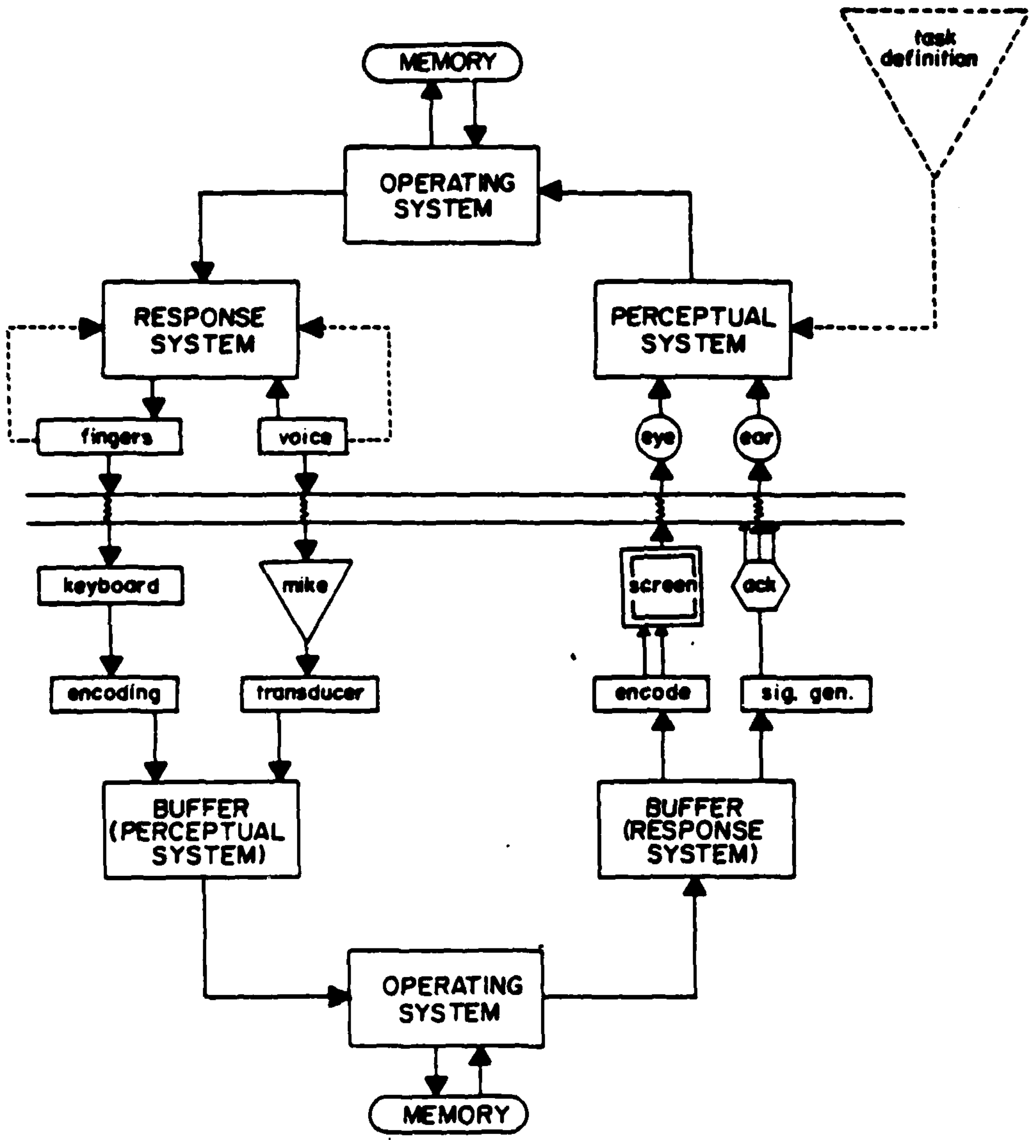

Figure 5. A more detailed schematic of Figure 4.

In the bottom portion of Figure 5 we represent the very general and essential characteristics of the machine; namely, its central processor, memory, input and output channels. At the top of the slide, we represent the essential characteristics of the operator; namely, input devices, composed essentially of visual and auditory sub-systems, output devices, composed essentially fingers for manipulating keys, pointers, mouse, lightpen, but also voice-activated capability. As one studies Figure 5, it becomes self-evident that the effective design of interactive systems requires somewhat detailed knowledge concerning human response times, limitations on visual image store, transfer rates between sensory systems and the human CPU, which we often refer to loosely as a cognitive system, and storage and retrieval rates to and from memory.

V A FEW COGNITIVE CONCEPTS

The knowledge that exists concerning human performance characteristics is based upon careful experimental methods, in the psychological laboratories of a relatively small number of behavioral scientists, almost exclusively in the United States. Studies of human performance characteristics can provide information that is useful, and at times necessary in the design of man-machine systems. For example, it is well-established that roughly 100ms. is required to encode the analog information residing in.a human visual "image buffer" and to pass the symbolic information to working memory. Also well-established is the finding that the cycle time of the human "central processor" is roughly 70 ms. This means that approximately

70 ms. is required to transmit a bit or chunk of information from working memory to long-term memory, or from long-term memory to a working memory buffer, or to initiate a response from the memory buffer to the appropriate kinesthetic pathway.

We have also learned that human perceptual processes behave as parallel processors, and that central processes behave as serial processors. If a character must be interpreted, the process includes 1) perception of the character; (2) transmission of the character from the visual system to working memory; and 3) one or more searches of long-term memory to compare/match the character with a known concept. Most operator tasks can be analysed in this fashion, and because of the serial nature of central processing, the calculation of total (minimum) response time requirements can usually be specified as additive functions of the separate cycle times.

Research has also established certain limitations on short-term memory. We know, for example, that it is easily possible to overload working memory, as in instances in which spoken information is to be stored in long term memory. Humans are seldom able to retain more than seven discrete chunks of information transmitted to them, unless time is available for them to encode, associate and store the information in long-term memory. Also, research suggests that the capacity of long term memory is virtually infinite, but that information cannot be retrieved from memory unless it was labelled by the individual at the time it was acquired, and that labelling itself requires several cycles of our CPU, setting limitations in information transfer rates, and implying changes for machine-driven displays.

On the response side, we know how long it takes for a finger to position itself on a key or other target. Positioning time varies directly with distance to target, and inversely with target size, according to Fitts' Law. There is much more known about human capabilities than I can relate to you in this lecture. But as noted earlier, what we know is not always used well in system design.

This presents a disturbing inconsistency. Engineers engaged in system design may devote untold effort towards optimal design of I/O buffers, improved reliability of communication protocols, improvements in electronic messaging, etc., leaving little to chance. Yet their resources are such that they fail to deal with the equally important protocols which link man and machine in effective communication.

A variety of questions arise when we begin to think about these problems: Under what circumstances does the operator make ordinary response errors when pressing function keys? Under what circumstances does the operator fail to send a message? Fail to respond to a flag? Misunderstand an error message? Forget the code for a control command? Experience difficulty in processing information that is split between two screens? Open the wrong channel for communication? Send a message in a form not appropriate for the channel? These problems are the frequent result of poor interface design, and they are exacerbated by inadequate feedback in the loop. The problems most often result from failure to apply certain design principles which derive from the fields of cognitive psychology, linguistics, psychophysics, perception and learning;

principles which have been well established by empirical research in psychological laboratories and in industry.

VI INFORMATION TRANSMISSION IN MAN-MACHINE SYSTEMS

Normally, when we think about information transmission, we think of sending and receiving messages or data from a peripheral user to a central processor, or from one user to another, within the same network or system. However, when cognitive psychologists approach the problem of system design, information transmission refers as well to the communication that takes place between the user and the machine interface. In this respect, it is possible to single out two classes of problems for study; 1) transmission of instructions or commands from the user to the machine; and 2) transmission of information from the machine to the user. In the first case, the user sends a command to a machine, for example, by depressing a function key on the console, causing the machine to perform a series of instructions that have been pre-programmed to be executed in response to the key. In the second case, as the machine executes, its displays register its status and send that information back to the user.

It may appear that one should consider that feedback occurs in this second case, that is, from machine to operator, but not the first, from operator to machine. Is this the correct viewpoint? Actually, no. With the operator in the loop, the system is such that output from the machine is input (feedack) to the operator, and output from the operator is input (feedback) to the man. We must remember that adaptive systems are not simple machines. Information is

communicated from one node or component to another, but there is often more than one node at which the information received is evaluated, decisions reached, and actions taken, resulting in the transmission of processed commands to other nodes of the system. Therefore, there is no necessary functional difference between a node which happens to be human and one which happens to be electronic. The only differences are in the competences of the different nodes to perform their functions. It is known that nodes are more competent if supplied with information concerning the results of their actions, and this circumstance is, not coincidentally, the definition of feedback. Clearly, man-machine systems have a symmetry about them. Each component depends upon the other, directs the other, responds to the other, helps the other, and, in the case of systems of the 1990's, adapts to the other.

Figure 6 provides another kind of example of symmetry; this time for a system composed of two humans and a machine. In the top left portion of the Figure, information is passed from the machine to each person, while the two people exchange information and then communicate back to the machine. It appears from the Figure that the machine dominates the people; that it initiates commands, while the people react. In contrast, the system shown at the top right of Figure 6 appears to be quite different. In this case, two individuals confer and transmit information to the machine, which then transmits information back. It appears that this machine submits to the authority of its operators.

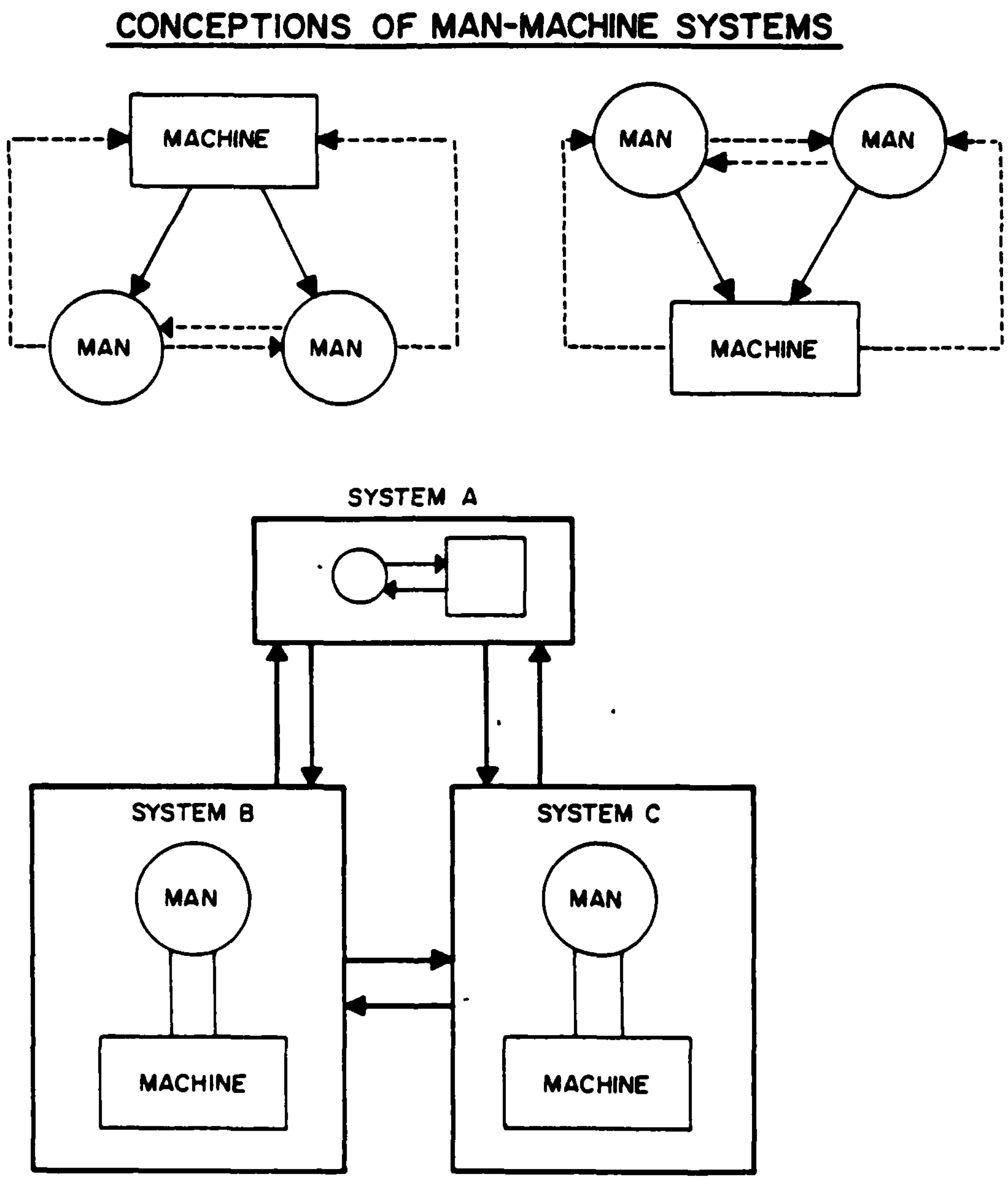

Figure 6. Symmetrical systems.

But who really submits to whom in interactive systems? The two systems just discussed are virtually identical, except that one has been sketched with the machine shown at the top of the diagram, while the other shows the machine at the bottom. The only apparent difference between these two systems is that one of them arbitrarily labels the flow of information from man to machine as feedback (shown by a broken line), while the other labels the flow of information from machine to man as feedback.

Is the difference real? To depict the two people in the system, we would not normally represent one of them as being the exclusive initiator of commands and the other as a more passive respondent. Perhaps after a more exhaustive analysis of the system in response to a variety of tasks, one might identify certain characteristics of speech and response that would lead to this conclusion, but such an analysis would require that the functionality of the system be understood in terms of certain psychological dimensions, such as the need for power, vanity, persistence, defensiveness, and so on. In the same way, it is neither the system configuration nor the conventional functionality nor the feedback loops which determine whether operator dominates machine or machine dominates operator. As in interpersonal relationships between two individuals, domination and submissiveness between operator and machine is based upon those psychological characteristics which are left free to operate within the context of the integrated system.

As a final note to this section, I would like to mention that a complete view of man-machine systems includes interactions between two

or more man-machine systems. This is shown at perhaps the simplest possible level of complexity in the bottom diagram of Figure 6. Needless to say, there is considerable potential here for software design which is adaptive to the task requirements and psychological characteristics of the operators of these systems, for the psychological processes embedded in a single man-machine system are simple in comparison with psychological processes embedded in multi-node systems.

VII PSYCHOPHYSICAL FACTORS VS. COGNITIVE FACTORS

This paper can provide no more than a brief brief overview of our state of knowledge of human factors and cognitive factors as these apply to interface design of adaptive systems. Let me offer only a few general comments. Our knowledge concerning human factors includes a rather detailed understanding perceptual and response mechanisms, which are traditionally referred to as psychophysical factors. The limitations of our perceptual systems have been well-defined by lawful relationships between stimulus characteristics and operator response characteristics, and the parameters of these functions are known to be invariant over a wide variety of conditions.

PSYCHOPHYSICAL FACTORS	SYSTEM DESIGN ISSUES
Finger movement speed	Types of controls
Eye-hand coordination	Keyboard layout
	Joystick, levers
	Mouse, lightpen
	Location of controls
	Dynamic feedback chracteristics
Visual acuity	VDT characteristics
Visual contrast effects	Luminosity
Color vision	Raster
	Contrast
Visual search time	VDT text and graphics
Visual scan, eye movements	Character size
Reading speed	Fonts
Discriminability	Graphics symbols
	Formatting of displays
Auditory acuity	Audio signal characteristics
Signal processing/discrimination	Dominant frequency
Speech intelligibility	Spectral chracteristics
	Speech synthesis

Figure 7. Some psychophysical factors and related design problems.

Information is readily available concerning perceptual thresholds, eye/hand coordination, visual search and discrimination, auditory sensitivity, and other aspects of human visual and auditory sensitivity. Additionally, peripheral response mechanisms, such as visual tracking speed and accuracy, finger dexterity, response accuracy, etc. are reasonably well-understood. Some of these are enumerated in the left-hand column of Figure 7. Stevens' Handbook of Experimental Psychology and McCormick's Handbook of Engineering

Psychology remain valuable source for this information.

In the right-hand column of Figure 7 are displayed some of the design issues which can be properly addressed only with cognizance of the limitations imposed on human operators by the natural limitations in sensory, perceptual and tactile-kinesthetic factors. Much of this body of information has been employed in the design of CRT's, keyboards, touch-screen systems, and so forth, where attention has been given to the operating characteristics of human perceptual and response systems.

In the left column of Figure 8 we display some of the cognitive factors studied in the psychological laboratory. In lay terminology, cognitive processes are considered to be mental, or central, as opposed to psychophysical/kinesthetic, or peripheral. This list includes working memory capacity, cognitive organization and representation, short term and long-term forgetting, memory search and retrieval times, memory interference, human reasoning, problem solving, and decision-making. A good deal has been learned about these processes also, though there is much that we do not fully understand. For those of you who are interested in learning more about the role of cognitive factors in human operator performance, a text by Card, Moran and Newell is an excellent source.

COGNITIVE FACTORS	SYSTEM DESIGN ISSUES
Working memory (space) capacity	Command Structure
Cognitive Processor cycle time	Tree vs. single-level
Working memory decay rate	Prompts, Menus
Long-term memory access time	Override capability
Memory interference, intrusions	Command syntax/semantics
Human reasoning processes	Speed of system response
Operator decision models	Error diagnosis systems
	System status information
	Multi-tasking environments
	Symbolic graphic representation

Figure 8. Some Cognitive Factors and associated system design issues.

In the right-hand column of Figure 8, we show a variety of internal design and software-related factors which depend upon knowledge of human cognitive functioning, and which are of concern to system design engineers. These include the command structure, speed

of response, error diagnosis systems, help systems, prompts, menus, customization, command syntax and semantics.

It is not immediately obvious what kinds of information are required from cognitive psychology in order to more effectively design the system interface, nor can we include this considerable amount of detail in the present paper. However, some insight can be gained by refering to Fig. 9.

Figure 9 is organized so as to depict the "man factors" arrayed on the left, and the "machine factors" on the right. These factors are also ordered vertically, from the simple to the complex. The top half of the Figure is composed primarily of psychophysical factors; the bottom half consists of some cognitive factors. The linkages between these are suggested by the connecting lines. Figure 10 merely emphasizes the fact that attention to both the human operator and the machine are necessary for proper interface design, and that proper attention to these components should improve both ease of learning and ease of use.

Are there examples of good interface design in the marketplace? Indeed there are, but they are quite rare. It has only been within the past two years that cognitive and experimental psychologists became engaged in significant numbers as consultants to electronics manufacturers, and the results of this transition are only beginning to be visible in sophisticated new products. This morning, I met with Dr. Avshalom Aderet, whose office is in Tel Aviv, Israel. Dr. Aderet presented a demonstration of interface software that was being

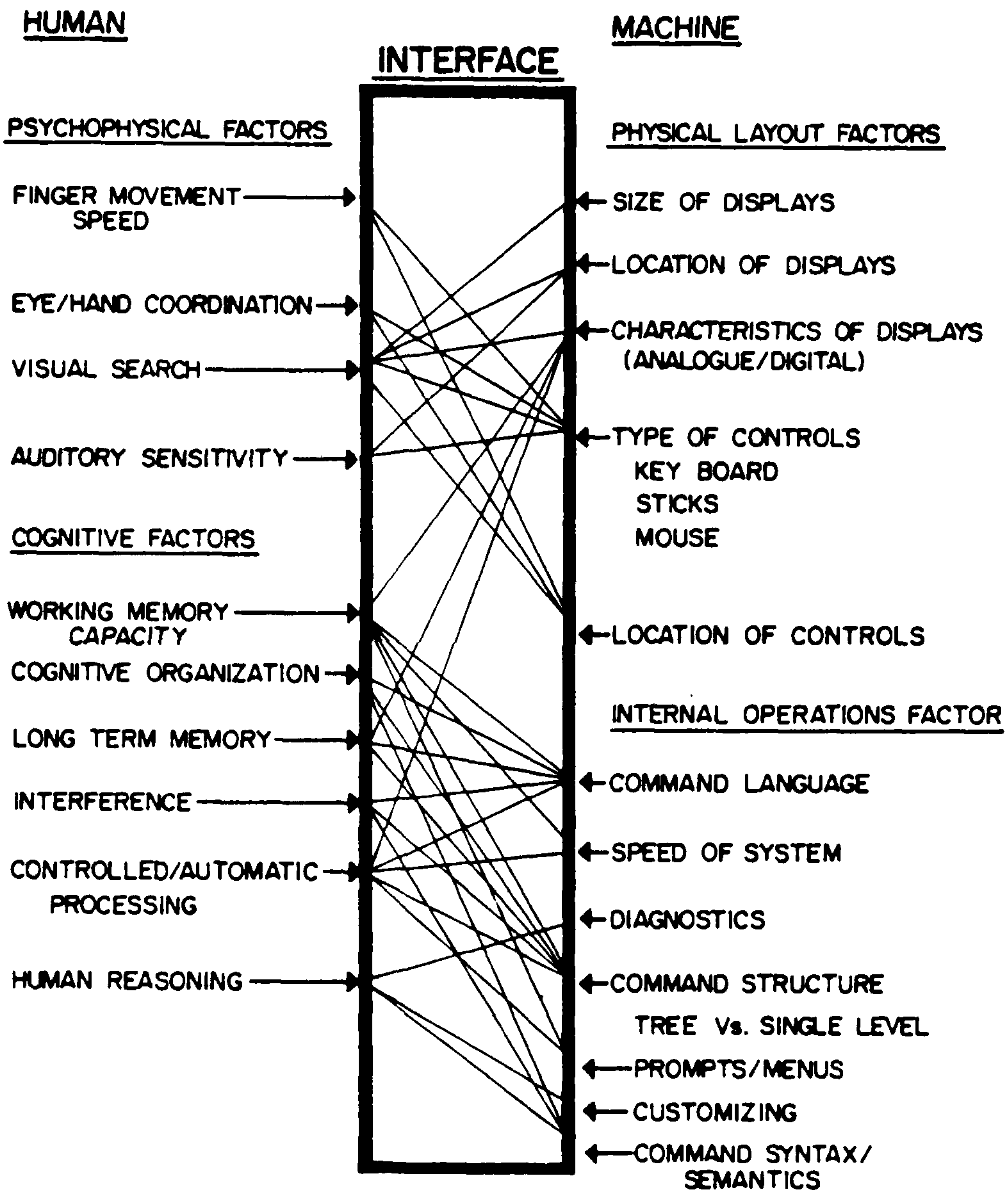

Figure 9. Matcnup of psychological factors and system attributes for effective interface design.

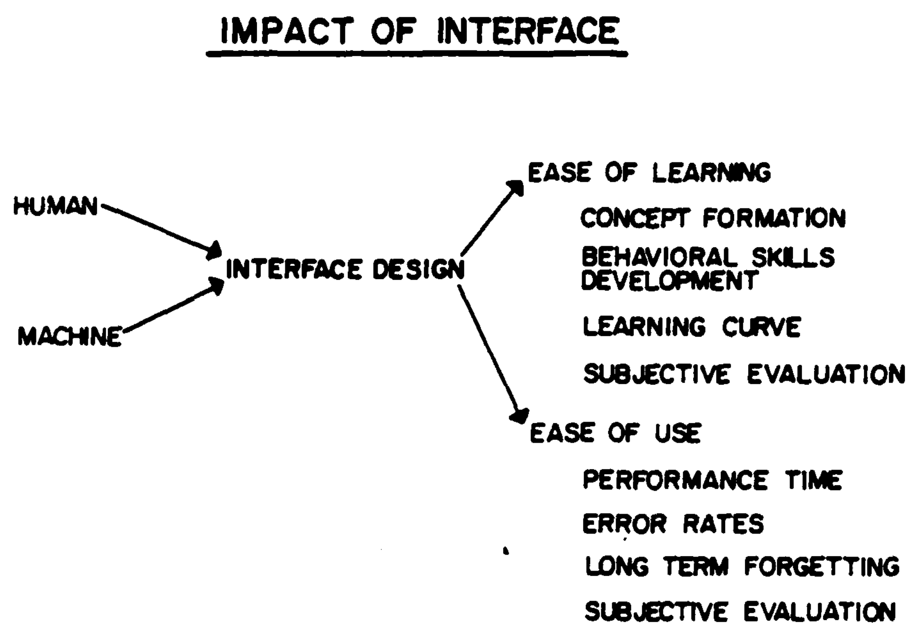

Figure 10. Impact of interface design on useability criteria

developed for touchscreen telephone terminals. Here one can see careful application of cognitive principles to the design of a system which, perhaps soon, will make possible automatic dialing, personalized directory updating, messaging, and applications integration, all at the touch of a finger, requiring virtually no introduction, manuals, or specialized operator training.

VIII INTEGRATED INFORMATION AND DECISION SYSTEMS

While progress in the development of productive capability is describable as a monotonically increasing function of time, the introduction of low-cost, high-capacity computing into the loop has produced a quantum step of progress. The magnitude of the impact is due to the central importance of two processes; 1) information processing; and 2) decision-making. These two processes are dominant controlling factors in automated systems. Whereas, until recent times, information processing and decision-making were functions undertaken by human operators, in modern systems we see these functions increasingly taken over by the machine. This has both beneficial and detrimental consequences.

On the positive side, creatively designed data base systems, managed by efficient storage and retrieval software, make available to the user enormous capability for the synthesis of information. These tools assist users in the achievement of understanding of the relationships inherent in the task under their control. They assist us in the planning of work. Software tools for flowcharting and PERT-charting are increasingly being used in industrial and other

settings. Other software tools help to identify certain relationships inherent in production processes, and we have spreadsheets such as SUPERCALC and LOTUS 1,2,3 which are now widely used. There are information systems which can guide us; telling us where to look, and who to see to get more information. Computer-based decision aides are capable of providing real-time guidance in choosing among complex alternatives, and simulation systems are becoming available to suggest alternative long-term consequences which follow from given decisions. It is worth noting that these applications software packages were NOT commercially successful until they had been designed to be at least reasonably user-friendly and easy-to-learn systems.

I am often asked if AI (Artificial Intelligence) systems are user-friendly. Surely, many of them appear ostensibly to have a captivating conversational style, but user-friendliness is more than a glib tongue, and if expert systems require prolonged interactions in order to either acquire knowledge or to identify a problem, the mere length of a session may exceed the patience of the user. There are serious problems of knowledge representation and analysis which remain unsolved within the field of artificial intelligence. On the other hand, quasi-AI systems are available which will, in somewhat more finely specified circumstances, offer integrated decision-aides that may be superior.

On the negative side, increased automation of functions previously performed by humans reduces the meaningfulness of work. Of equal importance is the fact that these systems rob individuals of the experience of working directly with the essentials of problems for

which they are responsible, thereby degrading the level of skill required of individuals, and increasing their dependence upon the machine. Increased opportunity then exists for error in the design and programming of algorithms, in the integration of large amounts of information, and in the application of the results of an analysis or process to a given problem. When such errors occur, operator confidence wanes, and frustration increases.

The psychological processes of trust and respect are not fully understood, but we do know that trust and respect are based upon expectations concerning behavior. It is clear that we generally hold machines to a higher standard of reliability and rationality than we do our fellow human beings. Then, when errors occur, either through system unreliability, inappropriate models, or inappropriate data, we are quick to experience feelings of betrayal, frustration and anger, even though those same errors, if committed by a colleague, might be easily forgiven and understood.

While it is the task of engineers and systems analysts to design the machines of the 1990's, the problems most frequently encountered require, for their solution, increased understanding of the psychology of the operator. Just as any component of a system must be understood in terms of its operating characteristics, reliability, and potential for malfunction, so the operator, as a component of the system must be understood in terms of those distinctively human operating characteristics which are required for effective system functioning. These include perceptual processes, cognitive processes and response processes, as well as those attitudinal and motivational factors which

are heavily dependent upon the conditions of work and task definition. To address these problems, engineers and analysts in the more advanced R & D laboratories are being guided by engineering psychologists with special training in cognitive psychology, including the design of displays, the human engineering of software, and the modelling of decision processes; i.e., knowledge engineering and expert systems development. These kinds of cooperative endeavors will more surely lead to the design and production of systems which satisfy criteria of useability, minimize the likelihood of serious error and improve efficiency, while at the same time providing challenging work opportunities and high morale for the workforce.

It is important to understand that while the increased capability of integrated, intelligent systems may reduce the quantity of detailed work required of the human operator, it does not reduce task difficulty. Instead, jobs occupied by operators are being redefined so as to increase individual responsibilities and to increase the complexity of the operator's tasks. At the same time there arises a demand that tasks be performed in entirely new ways, using symbolic representations, communication processes and control mechanisms which are unfamiliar, troublesome, and frustrating. The result is that the cognitive capabilities required by the tasks may exceed the cognitive limitations of man. One can visualize command and control systems of the future, in which sophisticated sensing systems feed large volumes of data into data systems for processing at lightning speeds, in the expectation that decisions can be communicated electronically to the field for immediate action. Yet, because of the need for human

oversight, a headquarters staff will doubtless remain in the loop between lightning-speed input and lightning-speed output, as though wired in series! The achievement of lightning-speed decisions for such systems represents what is potentially the most frustrating problem with which we will have to deal in the 1990's.

IX SUMMARY

There is no easy way to summarize these comments, for this paper has offered a very limited sketch of what we know, and an even more limited set of specifics concerning the role of cognitive psychology in the solution of these very complex problems. Let me instead offer further comments concerning both the positive and the negative side of our future. It will be the challenge of the next few years to design systems which include meaningful, problem-oriented dialogue at the user-interface. This should include self-contained, individually-paced training, guidance in problem specification, and certain machine-based consultant roles for the analysis and evaluation of the quality of problem solutions. Man-machine systems will need to be designed so as to make the best and most efficient use of those qualities of operators which humans can do best.

Of more importance is the need for machines which are capable of adapting to the unique requirements of a defined job environment. We will begin to abandon our traditional way of classifying jobs, e.g., typist, bookkeeper, manager, engineer, and will begin to speak of work in terms of tasks and functions. Each defined task or function will

imply a system for its management; a system composed of people and machines configured so as to accomplish the tasks required. We should therefore see changes in the way in which we conceptualize machines, and we can expect to see machines of the future which have considerably more flexibility. By this I mean not merely software compability. Both the functionality and the user-interface of the machine will vary both with respect to the task requirements and the limitations, idiosyncracies and role-definition of the operator.

Two other important changes are in store for us. First, as traditional job classifications give way to new, task-oriented dscriptions, the nature of work will change, in many instances introducing into formerly routine jobs new demands for judgment, decision-making and collaborative effort. Second, the increased obsolescence of jobs, along with the increased productive capacity of efficient man-machine systems will have effects upon manpower supply and demand that are extremely difficult to project. Dislocations from farming and manufacturing jobs have so far been largely offset by increases in white-collar jobs, including the electronics industry itself. But we do not know how societies will adapt to obsolescence of white-collar jobs. Also, the Age of Technology has produced massive relocations of our populations from rural areas to centers of technology, and plans do not exist for the solution of those future economic, social and spiritual problems which will accelerate as technology centers themselves fall victim to job obsolescence.

It should be clear to all of us that our remarkable technological developments are going to be a part of the tide of something we call

progress, destined to carry us, perhaps like lifeboats on a troubled ocean, to an uncertain future. Our new man-machine systems have the capapability of producing a greater volume and improved quality of goods and services, to be shared by increased numbers of people, but they also have the capability of altering our values, our sense of satisfaction, and our feeling of community in ways that cannot presently be imagined. It is not self-evident that the tide of innovation and progress will leave to our children the same opportunities, the same cultural values, the same potential for exploitation of natural resources. It is only certain that changes are inevitable. Rather than accept these changes passively, some of us will try to grapple with the larger task; to identify meaningful long-term goals which transcend immediate materialistic urgencies, and to steer a course that will enable us to enrich our futures with educational, cultural and spiritual necessities, while achieving greater security and an improved standard of living for all.

We must remain clear about our objectives in the broadest sense, and work to bring them to fulfillment, for while a world without machines is a world of adversity and drudgery, a world of machines without wisdom is at best a world of meaningless comfort and false security. Either of these futures is unhealthy for the survival of civilized mankind. Innovations in man-machine systems can and will yield substantial productivity gains, just as they have in the past. But no one presently knows whether these changes will, in the long term, improve the overall well-being of mankind.

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